TECHNICAL NOTE

1150-12 (ALS)

11 February 2003

MAXIMUM +Gz LIMIT - CENTRIFUGE SAFETY SYSTEM REQUIREMENT

A maximum limit for inadvertent +Gz (headward acceleration) exposure is a Safety System Requirement for the DRDC-Toronto centrifuge (Michas 2003). The purpose of this Technical Note is to document the available evidence describing the maximum +Gz level safely tolerable by human centrifuge riders.

Review of Data and Experience

In the investigation summarized in Figure 1, five subjects were exposed to 6, 8, 10, 12, or 15 +Gz for incrementally-increasing time periods until unconsciousness or cerebral confusion was produced. There was no sharp pain or abnormal cardiac rhythm among the centrifuge riders, or "evidence of permanent irreversible damage" (Beckman, Duane et al. 1954). The mean time at +Gz plateau to produce unconsciousness at 12 +Gz (1.64 sec) is approximately one-half that at 8 +Gz.

Figure 2 shows 40 data endpoints from approximately 300 experiments up to 15 +Gz (Stoll 1956). No consequences other than cognition and vision symptoms were reported. The vertical asymptote of total acceleration time to attain the endpoints is approximately 2.5 sec For some subjects, this occurred at 2 sec.

Chambers' review of both impact and sustained acceleration data from five other references is condensed in Figure 3 (Chambers 1963). The relationships between tolerance time and acceleration intensity is partially speculative since some intermediate data was not available. 11 and 12 +Gz can be endured for approximately 4.5 and 2.5 sec, respectively.

Figure 4 is also a compilation of human acceleration tolerances from several sources (Fraser 1966). The points represent acceleration plateaus for voluntary tolerances of subjects. That these were not working levels was stressed. There is no experience beyond 15 +Gz for approximately 1.5 sec.

Snyder's summary of two datasets of human and animal exposures to brief accelerations and decelerations is shown in Figure 5 (Snyder 1973). The zone for inconsequential exposure is bordered by 10 +Gz for 0.1 sec and 5 +Gz for 1.9 sec. Ejection seats produced 20 +Gz for 0.5 sec. Data from more sustained, but still brief acceleration exposures was not the primary purpose of Snyder's review.

During the 1990s, DRDC-Toronto developed extensive experience with exposures up to 9 +Gz in the centrifuge as part of programs of research with human subjects and training of pilots. These were conducted within the 12 +Gz medical limit recommendation of the institute's Central Medical Board (Salisbury 1992).

A recent description of advanced G-protective equipment reported that the average 15 sec tolerance of six subjects was 11.4 +Gz. Post exposure examination using spinal and head magnetic resonance imaging indicated no central nervous system sequelae. However, changes were noted after visual, neuro-cognitive and auditory-vestibular tests (Burns, Ivan et al. 2001).

Recommendation

The data of Beckman, Stoll and Chambers have been superimposed on the relevant portion of Figure 4 and reconstructed in Figure 6. Fraser's +Gz-time limitation curve transects these data. Above 9 +Gz, a border is developed by two data points: (i) 12.5 +Gz at 1.4 sec, and (ii) 10 +Gz at 1.6 sec. Until the need to expose beyond is justified, it is prudent to accept these points as maximums. This author recommends that human exposure to +Gz not exceed the region delimited by the double line (═══) in Figure 6.

This is not to imply that exposures to levels less than this boundary are without risk. A small proportion of centrifuge riders have developed problems (Whinnery and Gillingham 1983) and musculo-skeletal injuries are recognized among pilots of fighter aircraft (AMP Working Group 17 1994). Routine exposures must still be rationalized on the basis of necessary training or approved research. This recommendation only addresses safety system requirements in the event of inadvertent +Gz exposure.

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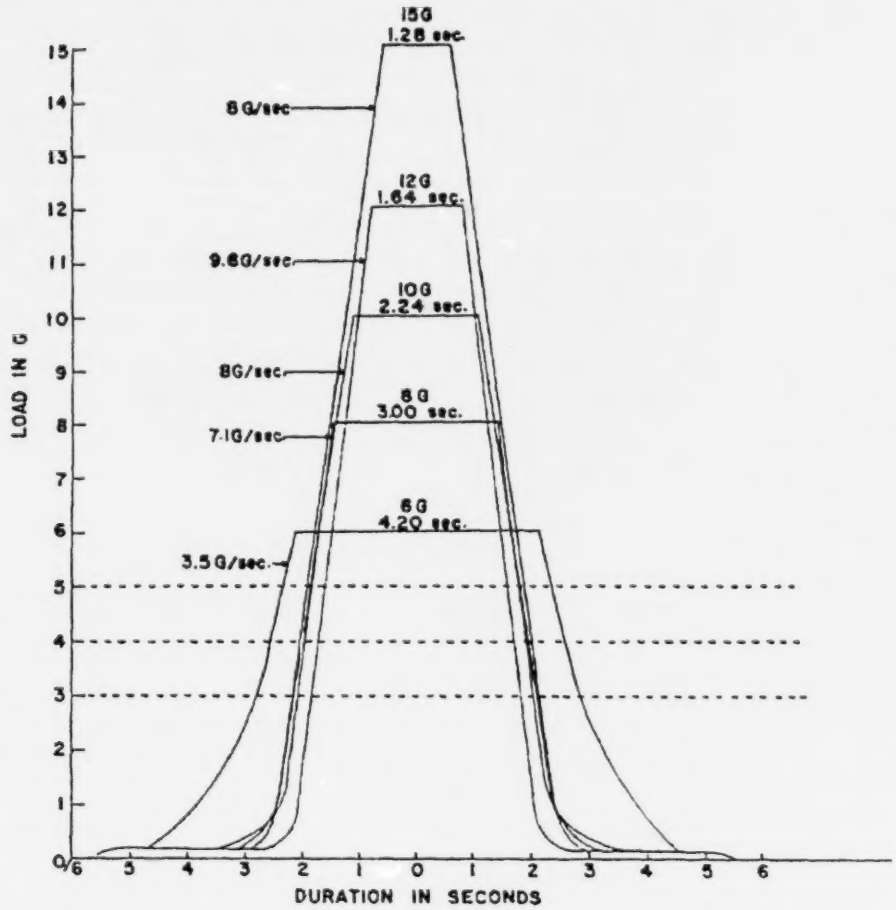


Fig. 3. Load curves of experiments which produced unconsciousness, constructed from mean values.

(Source – Beckman, 1954)

Figure 1

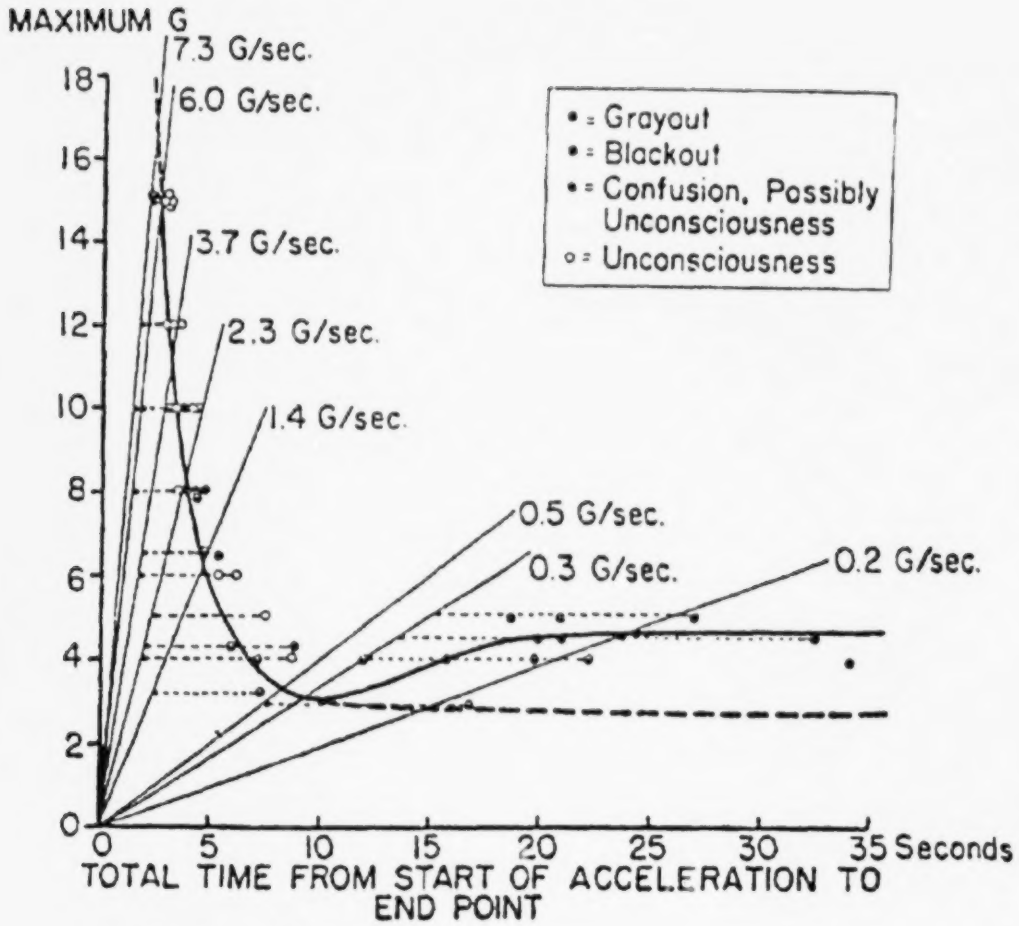


Fig. 4. G-tolerance curve with various acceleration rates.

(Source – Stoll, 1956)

Figure 2

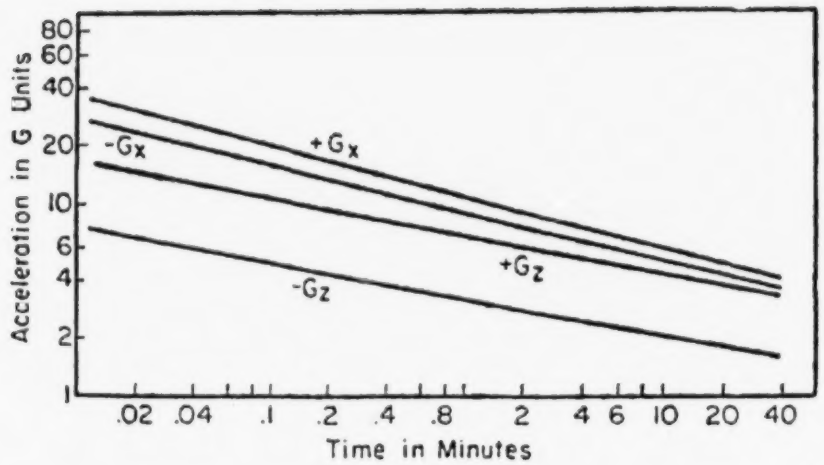


Figure 6. Average acceleration tolerance for positive acceleration ($+G_z$), negative acceleration ($-G_x$), transverse supine acceleration ($+G_x$), and transverse prone acceleration ($-G_x$). (Official photograph U.S. Navy.)

(Source – Chambers, 1963)

Figure 3

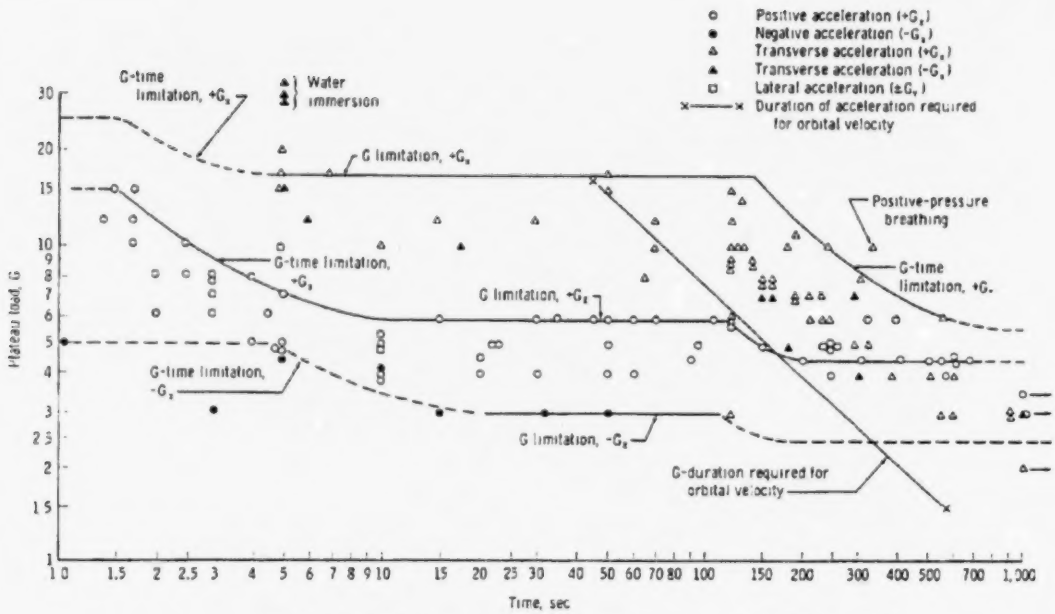
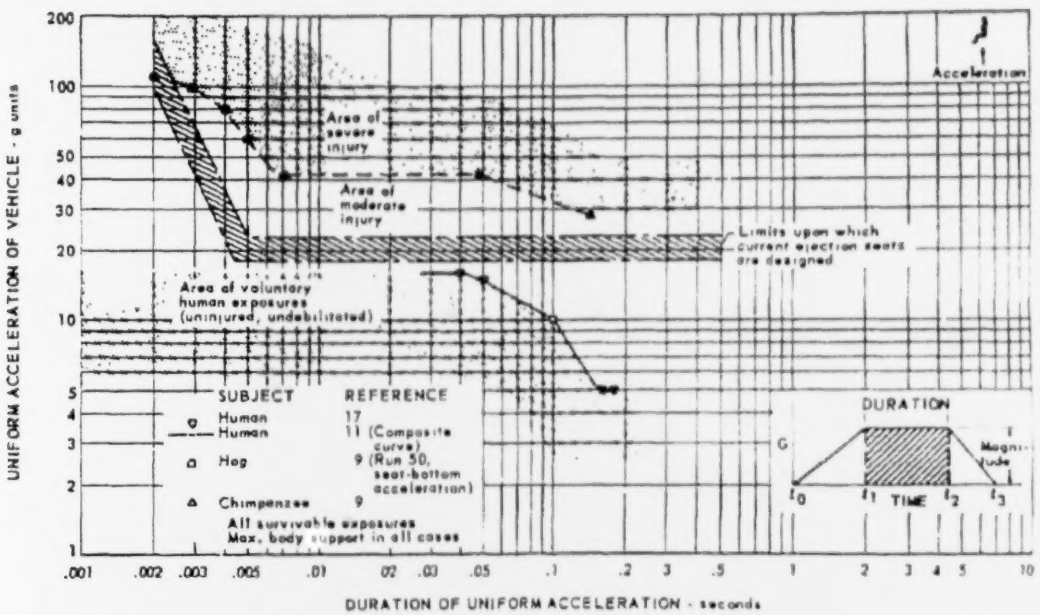


FIGURE 26—*Human experience of sustained acceleration* (Data from many sources)

From Fraser T M (1966) Human response to sustained acceleration NASA SP-103 National Aeronautics and Space Administration Washington D C

(Source – Fraser 1966)

Figure 4



(a)

Figure 6–6. Survivable abrupt vertical ($\pm G_z$) impact. Reference numbers are those in original reports. (After Webb, 1964; based on data of Eiband, 1959)

(Source – Snyder, 1973

Figure 5

Range of Experience with Sustained Acceleration (1-30 sec) and Recommended Limit for DRDC Toronto Human Centrifuge

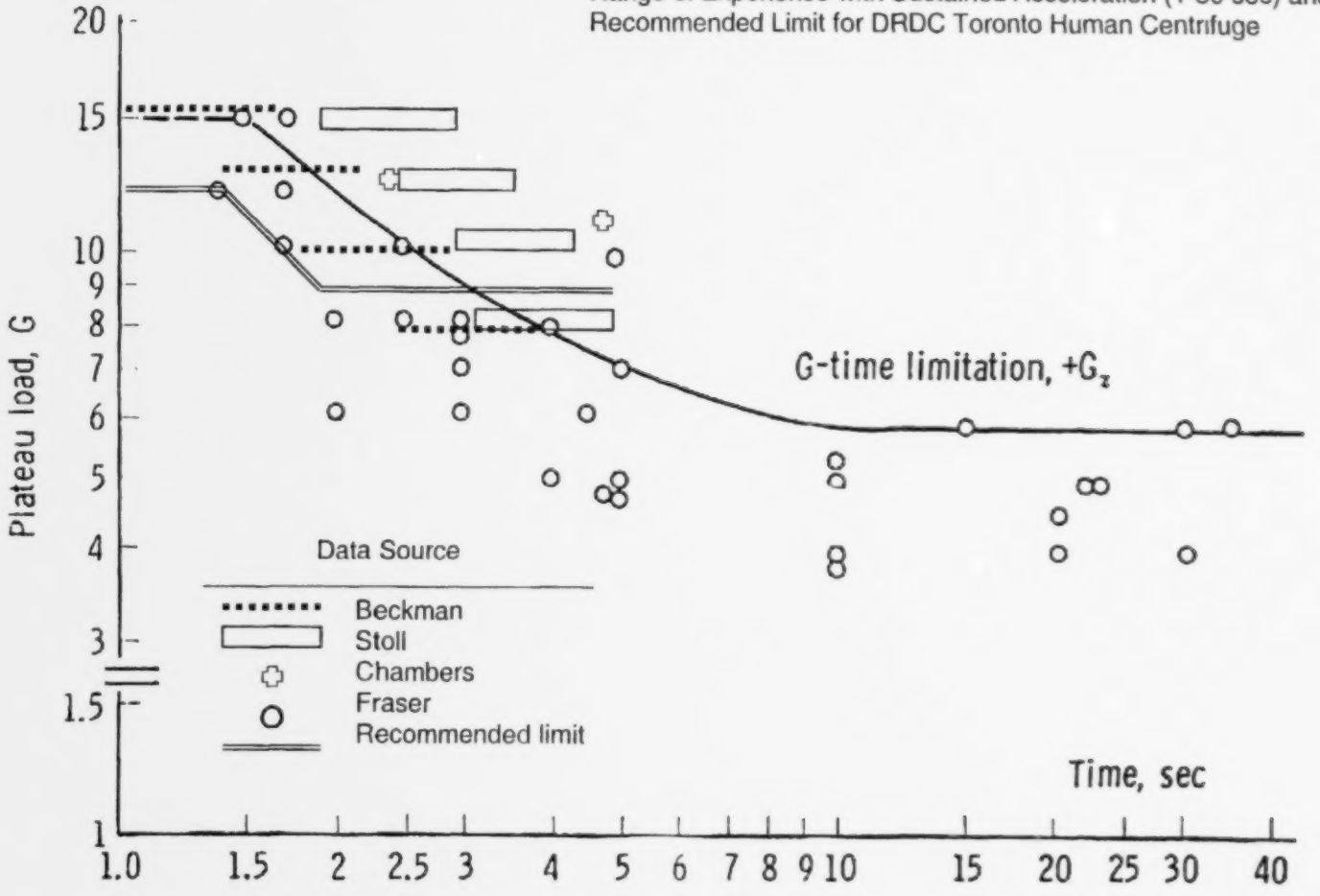


Figure 6

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